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12 GHz IMAGE AND SUM ENHANCED MIXER DIODE CONVERTER

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1.0 INTRODUCTION

The objective of this program was to develop, fabricate, test, and deliver five image and sum frequency enhanced mixer diode converters having the design goals as set forth in Table 1.

TABLE 1

	Design Goals	Measured Parameters	
RF Frequency Band	11.7-12.2 GHz	11.7-12.2 GHz	
IF Frequency Band	1.0-1.5 GHz	1.0-1.5 GHz	
IF Return Loss	≥ 10 dB	≥ 14 dB	
Overall Noise Figure, Band Center	6.2 dB	6.1-6.5	spread for
Overall Noise Figure, Band Edge	6.7 dB	6.7-7.2	5 units
Conversion Gain	≥ 15.8 dB	25 dB	
LO Frequency	10.7 GHz	10.7 GHz	
LO Power	≤ 20 dBm	+ 18 dBm	
3rd Order Intermodulation Product (IMP) Level for Twelve -75 dBm Carriers	≥ 30 dB below desired signals	see paragraph below	

The actual measured parameters on the five delivered units are also shown in the above Table.

The last parameter listed in the Table, i.e., 3rd order Intermodulation Product (IMP) level, was measured using two signals at a higher power level (-67 dBm) rather than twelve signals at -75 dBm. For two -67 dBm signals, the extrapolated IMP level was 127 dB below the desired output signals. When the

two input signals were increased to -25 dBm, the IMPs were still 44 dB below the desired output signals.

As can be seen by the Table, with the exception of noise figure which was typically a few tenths of a dB higher than desired, all other specifications were met or exceeded.

2.0 TECHNICAL DISCUSSION

2.1 MIXER DESIGN

A photograph of the mixer circuit is shown in Figure 2-1. The design is very similar to the earlier image and sum frequency enhanced mixer developed at Westinghouse[1] except for improvements to several of the more important filters in the mixer. The mixer and interstage network were fabricated on a single 0.75" x 1.50" x 0.025" sapphire substrate using thin film techniques. Components were mounted using AuSn solder. The diode lead, a 1 mil gold ribbon, was bonded using a thermal-compression wedge bonder.

A traveling-wave ring directional filter is used for LO and signal injection to the mixer diode. LO power entering port 1 is coupled over to port 3 with approximately 3.5 dB insertion loss. This transfer characteristic (port 1 to port 3) is bandpass while the signal path (port 4 to port 3) exhibits the complementary band reject characteristic. The loss to the signal is $\approx$.20 dB across the band.

The image and sum frequency filter on the RF input side of the mixer consists of two half wavelength (at the image frequency) open circuited stubs coupled to the main line over a quarter wavelength plus two open circuited stubs which are a quarter wavelength long at the sum frequency. The 500 MHz

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1. J. B. Cahalan, J. E. Degenford, M. Cohn, "An Integrated X-Band Image and Sum Frequency Enhanced Mixer with 1 GHz IF," <u>1971 International Microwave Symposium Digest</u>, pp 16 - 17, May 1971.

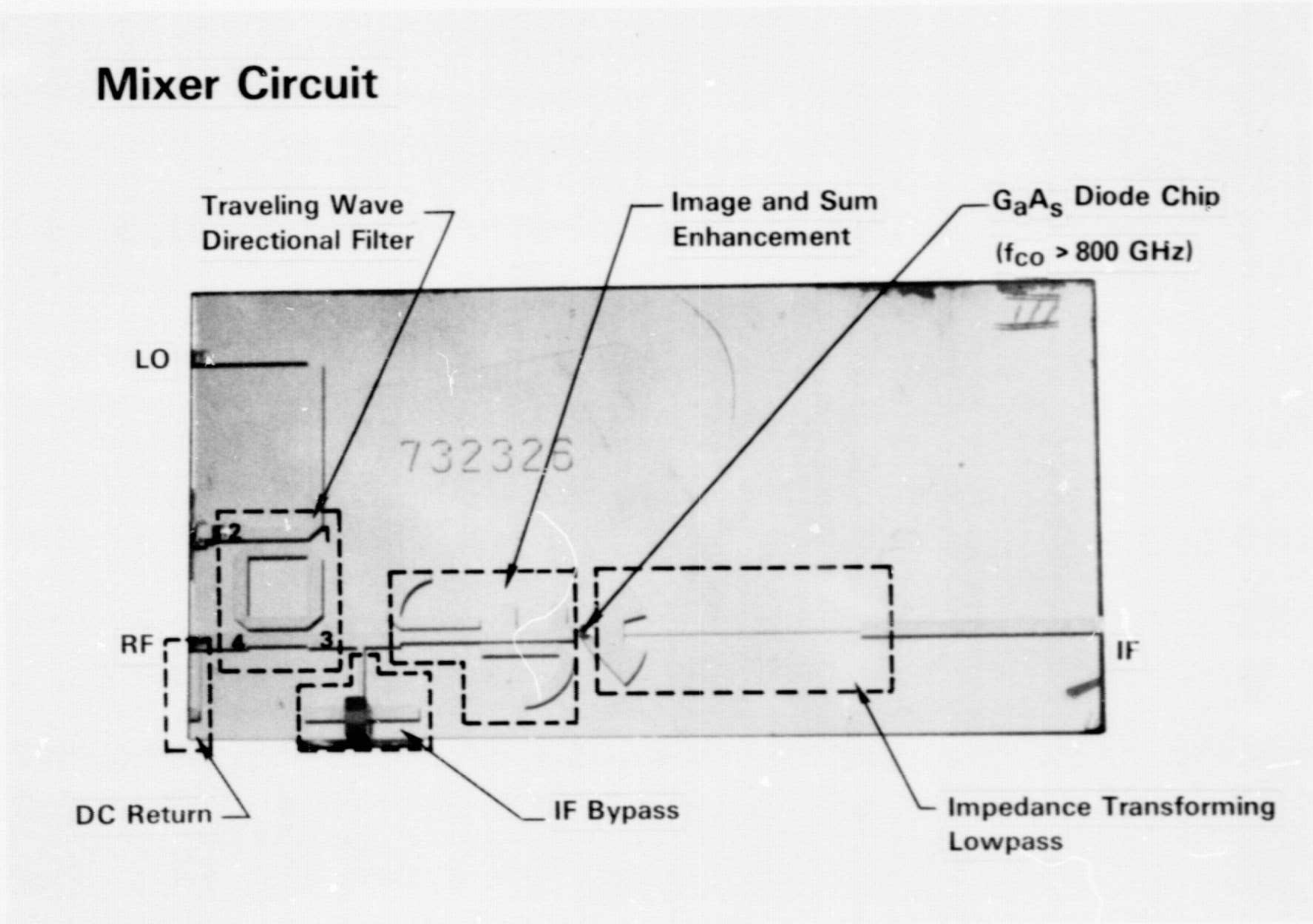

Figure 2-1. Mixer Circuit

bandwidth required for the image filter necessitated the use of a double stub design. The latter stubs are spaced a nominal quarter wavelength apart at the signal frequency so as to present a good match at the signal frequency. The measured characteristics of this filter are summarized below.

IMAGE AND SUM FILTER CHARACTERISTICS

VSWR, Image Band (9.2-9.7 GHz)	$>$ 25:1
VSWR, Sum Band (22.4-22.9 GHz)	$>$ 17:1
VSWR, Signal Band (11.7-12.2 GHz)	$<$ 1.4:1
Phase Deviation, Image Band (9.2-9.7 GHz)	$\pm 50^{\circ}$

On the IF output side of the diode, the image and sum frequency filtering is accomplished by the low pass filter shown in Figure 2-1. This filter must pass the IF (transforming from 100 Ω to 50 Ω in the process) and stop the image, LO, signal, and sum frequencies. This filter was designed exactly using low pass filter theory; however, during measurements on a 10:1 scale model, it was found necessary to experimentally alter the filter to improve its performance.

The final experimentally derived shape can be seen in Figure 2-1. The characteristics of this filter are shown below.

LOWPASS FILTER CHARACTERISTICS

VSWR, IF Band (1.0-1.5 GHz)	$<$ 1.4:1
VSWR, Image, LO, and Signal (9.2-12.2 GHz)	$>$ 25:1
VSWR, Sum Band (22.4-22.9 GHz)	$>$ 50:1

The IF bypass network is also shown on the figure and consists of a high impedance stub terminated by two low impedance stubs (all $\frac{\lambda}{4}$ at the signal frequency) plus a shunt capacitor to ground. This combination is transparent

to the signal, but is designed to be series resonant at 1.25 GHz thus preventing IF from propagating out the signal port.

Finally, a grounded $\frac{\lambda}{4}$ signal stub is used to provide a DC return for the diode current.

A plot of conversion loss versus RF frequency for one of the final units is shown in Figure 2-2. The minimum value at band center is 3.5 dB rising to 4.4 dB at band edge. The latter value is approximately 0.2 dB higher than expected and is probably due to slight filter mistuning at the band edge.

2.2 AMPLIFIER DESIGN

The amplifier design was directed towards the following specifications:

1)	Frequency:	1-1.5 GHz
2)	Gain:	23 dB minimum $\pm$ 1.5 dB
3)	Input VSWR:	Best noise figure match
4)	Output VSWR:	2.0:1 maximum
5)	Noise Figure:	2.5 dB maximum across frequency
6)	D.C. Bias:	12 v. (80 ma)

In the fabrication process, thick film microstrip circuit techniques were used in order to achieve high reliability, low cost, small size, and repeatability. The resistors were screened on the substrate using selected resistive inks, thus minimizing the number of components that require bonding.

The first design iteration was constructed on a 2 x 2 inch ceramic substrate. Three Nippon transistor devices were used in this design, NEC - V578A, 2SC - 1336, and V907. Among the considerations included in transistor selection across this frequency band were gain, noise figure, stability, and

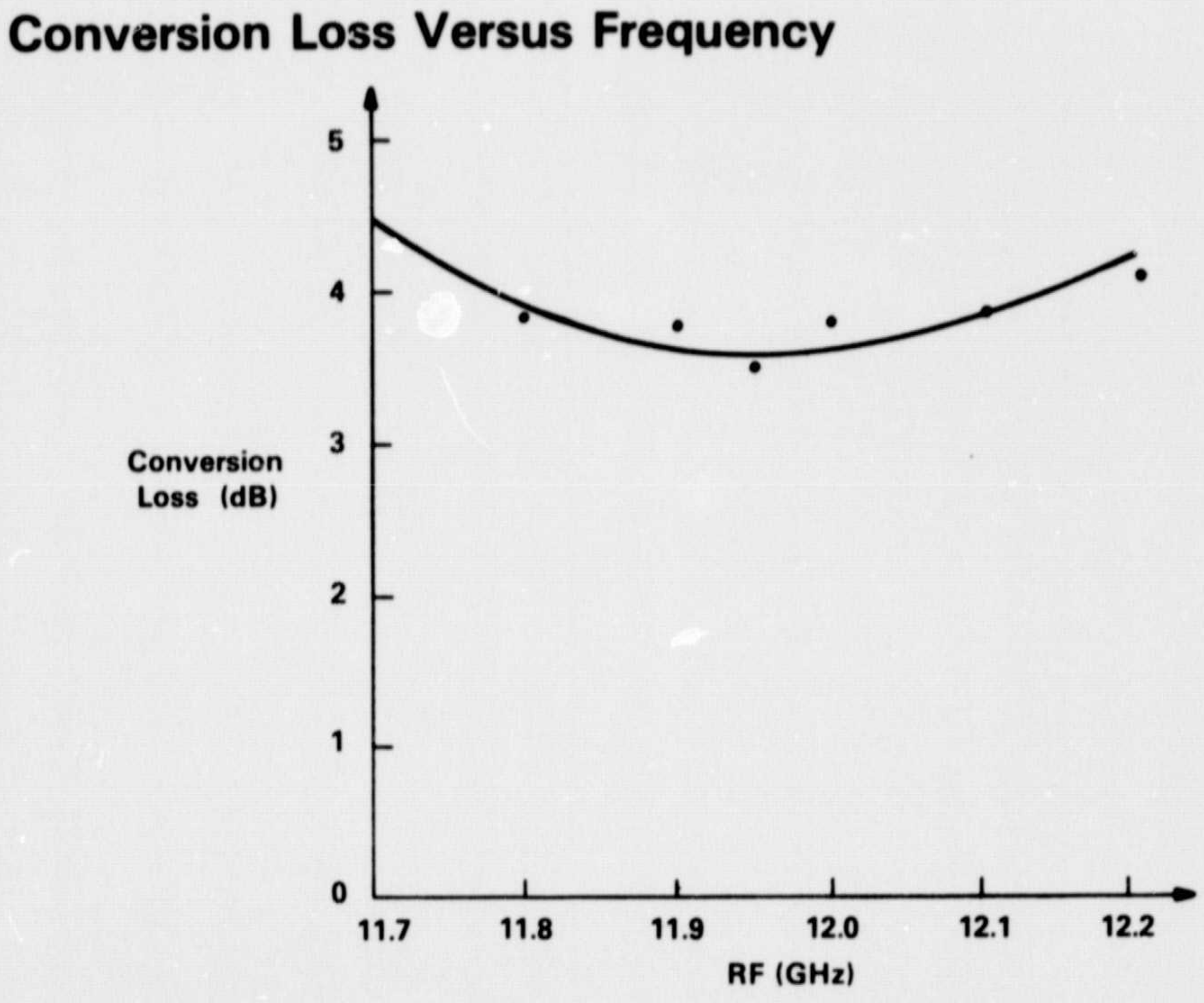

Figure 2-2. Conversion Loss versus Frequency

matching complexity. The S-parameters of each transistor device were characterized on an automatic network analyzer. A low-noise first stage transistor was selected for this amplifier and an optimum noise figure match for this transistor was obtained. Basic Smith chart matching coupled with computer techniques were employed throughout the design process. Due to line length considerations at L-band, stub matching was chosen over other techniques, such as, matching transformer sections.

The first amplifier design performed well, demonstrated that a 40% bandwidth could be achieved with stub matching techniques and met all specifications except for noise figure. This device measured approximately 3 dB at the high end of the frequency band.

To reduce the noise figure, a lower noise figure first stage transistor developed by Fairchild, the MT 4000, was evaluated. The schematic of this final design is shown in Figure2-3. Again, the optimum noise figure match was used for the first stage transistor. This circuit was constructed on a 2 x 2 inch ceramic substrate employing thick film techniques.

The new amplifier substrates were tested and again met all specifications except for noise figure. It was found that a very careful tuning procedure across frequency would bring the noise figure of the device to within .2 dB of the desired specification at the worse point. The noise figure system measuring accuracy was considered to be ± .1 dB. This accuracy figure causes the best and worst case noise figure deviations from specification to be .1 dB and .3 dB respectively. Five amplifiers were tuned using the above procedure and integrated with the mixer into the final housing. A plot of the performance of one of these units is shown in Figure 2-4.

Schematic L-Band Amplifier

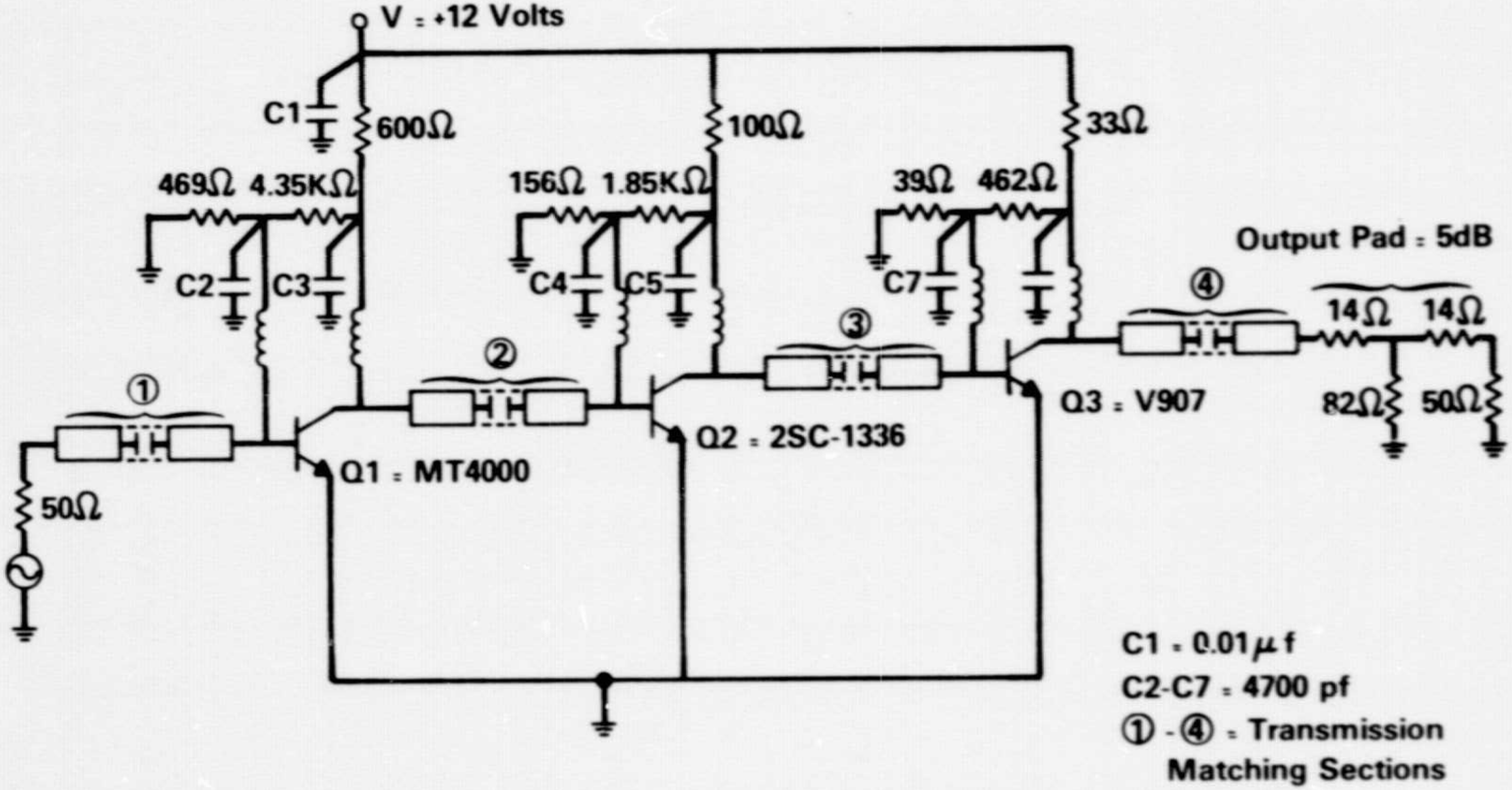

Figure 2-3. Amplifier Schematic

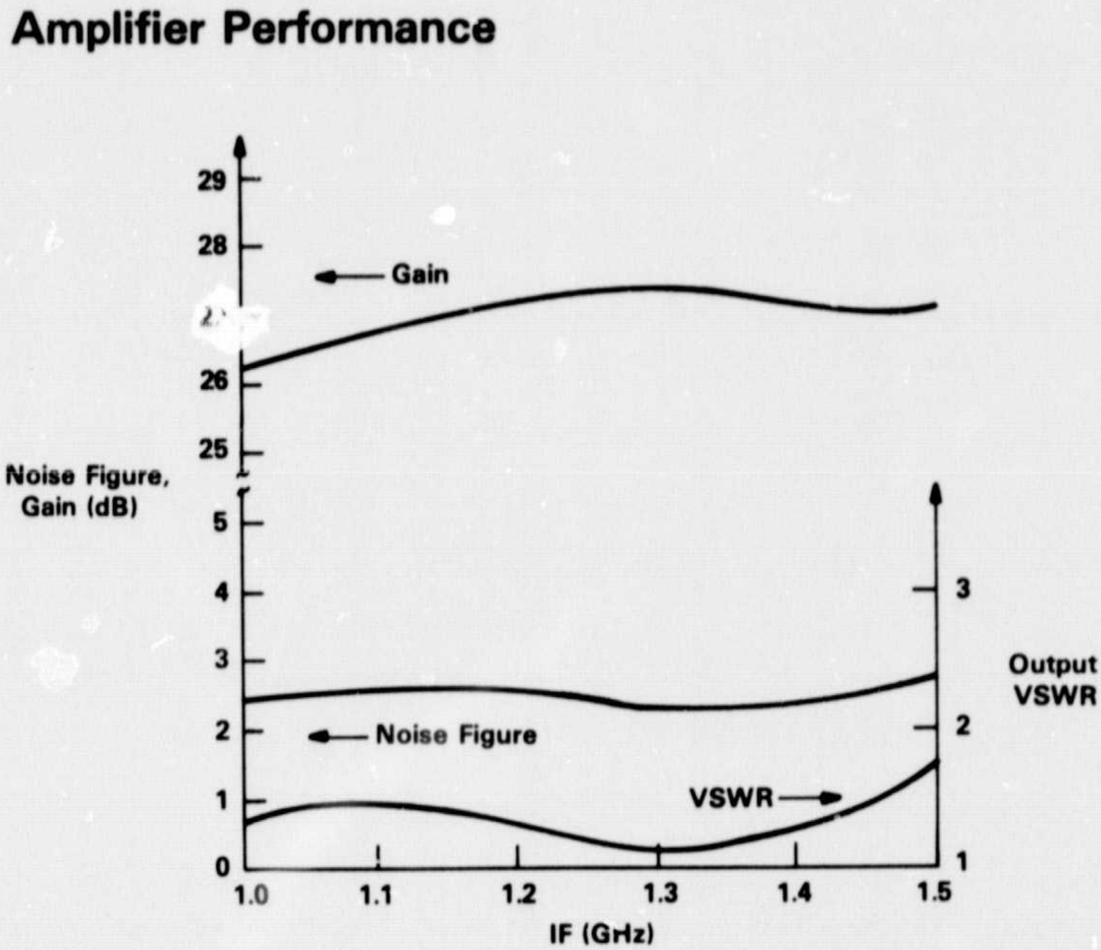

Figure 2-4. Amplifier Performance

2.3 INTEGRATION OF MIXER AND IF AMPLIFIER

Sufficient room was intentionally left on the mixer substrate to add an interstage matching network between the mixer and IF amplifier. The matching structures were determined experimentally by tuning for minimum overall noise figure after the mixer and amplifier were assembled in the final housing. The insertion loss of this matching structure accounts for the overall noise figure being slightly higher than the sum of the mixer conversion loss and IF amplifier noise figure. A photograph of one of the completed units is shown in Figure 2-5. The measured performance of the final delivered units is discussed in Section 3.0.

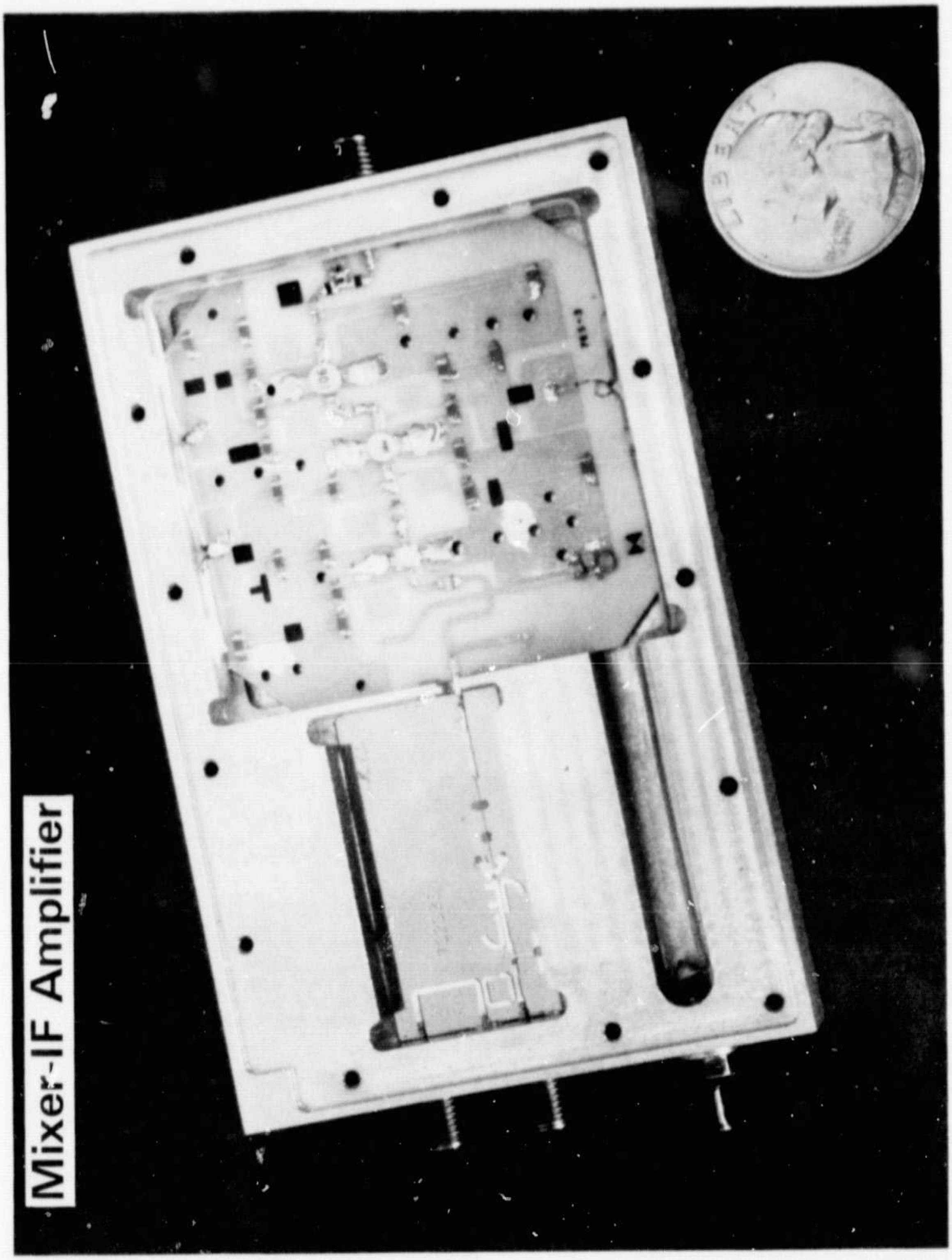

Figure 2-5. Photograph of Mixer-IF Amplifier

3.0 MEASURED PERFORMANCE ON FINAL UNITS

3.1 TEST PROCEDURES

Acceptance testing of the mixer-IF amplifiers consisted of the following three tests:

1) Conversion gain and IF VSWR using the set up of Figure 3-1(a).
2) Noise figure using the set up of Figure 3-1(b).
3) Amplitude linearity (third order intermodulation products) using the set up of Figure 3-1(c).

The performance of the measured units is shown in Figures 3-2, 3-3, and 3-4.

Figure 3-2 is a plot of the conversion gain spread for the five delivered units. As can be seen, the gain is nominally 25 dB with approximately 2 dB spread for the five units. The IF return loss was also measured at the same time as conversion gain and was always better than 14 dB.

Figure 3-3 is a plot of noise figure versus frequency for the five units illustrating the spread between units. Note that the mean value of noise figure is less than 6.7 dB over a band extending from 11.75 GHz to 12.15 GHz; rising to 7.1 dB at 11.7 GHz and 6.9 dB at 12.2 GHz. The actual noise figure for each delivered unit is also shown in tabular form on the figure for reference.

Figure 3-4 shows IF output and 3rd order intermodulation products plotted versus RF power for the case of two applied RF signals spaced

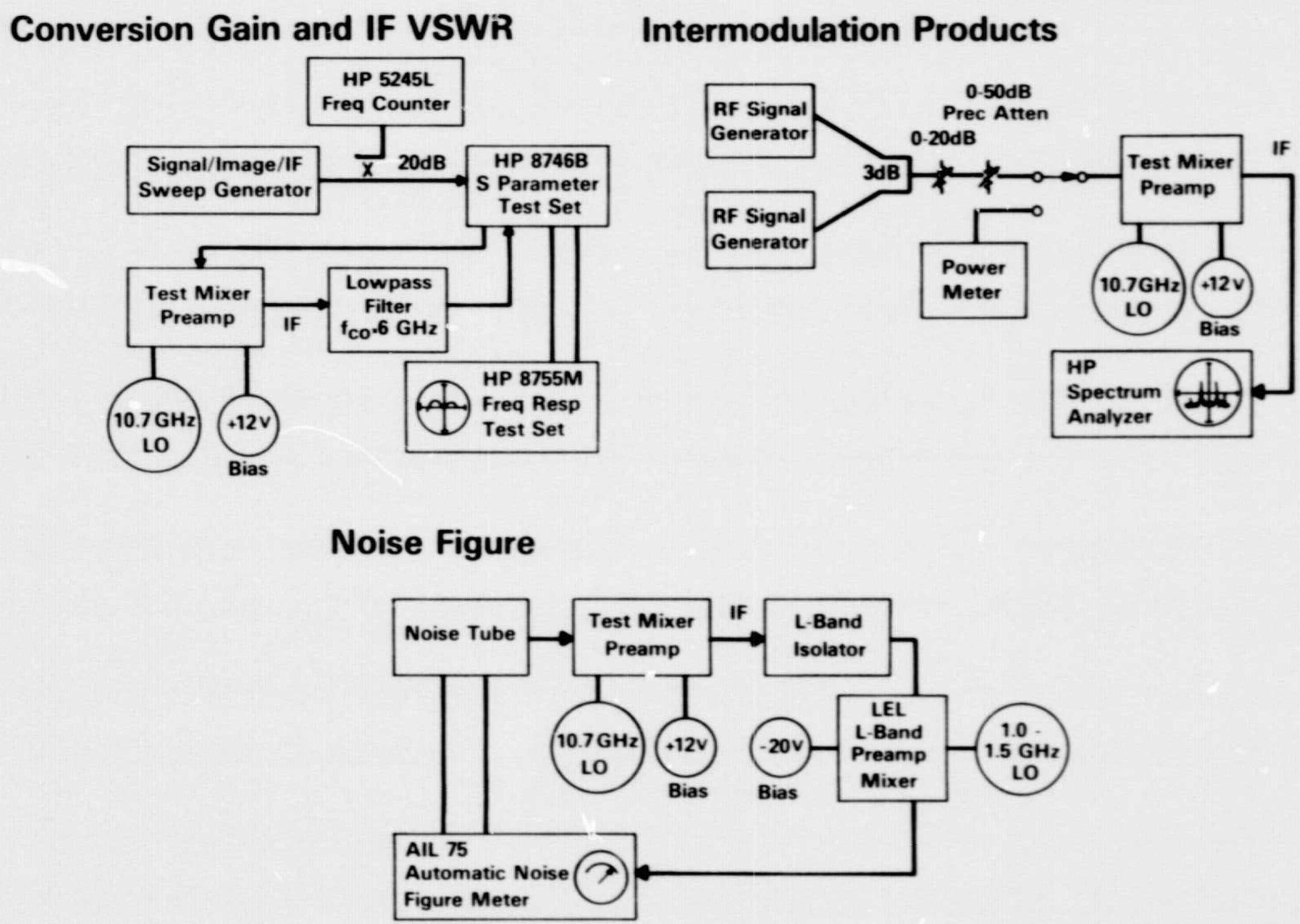

Figure 3-1. Test Circuits

Conversion Gain Versus Frequency

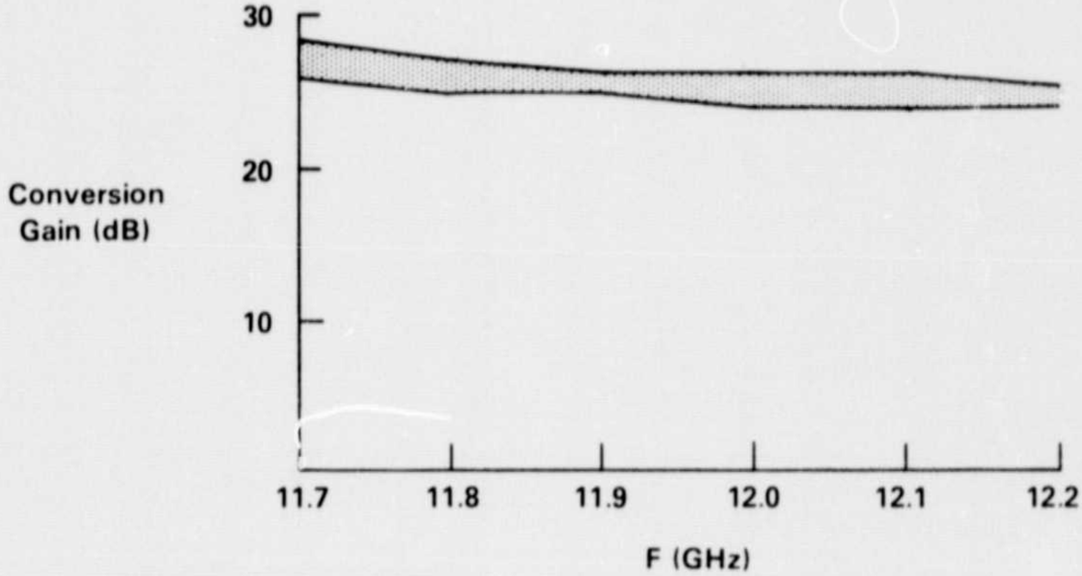

Figure 3-2. Conversion Gain versus Frequency

Noise Figure Versus Frequency

F (GHz)

S/N	11.7	11.8	11.9	12.0	12.1	12.2
001	7.0	6.3	6.1	6.5	6.5	6.8
002	7.1	6.3	6.3	6.7	6.5	6.7
003	7.0	6.2	6.3	6.6	6.6	6.9
004	7.2	6.5	6.5	6.6	6.6	7.0
005	7.1	6.4	6.3	6.5	6.6	7.0

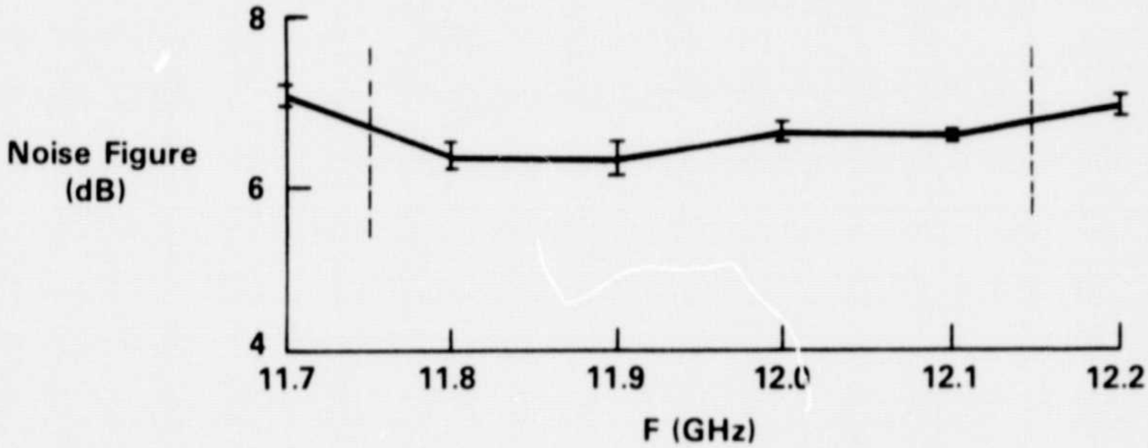

Figure 3-3. Noise Figure versus Frequency

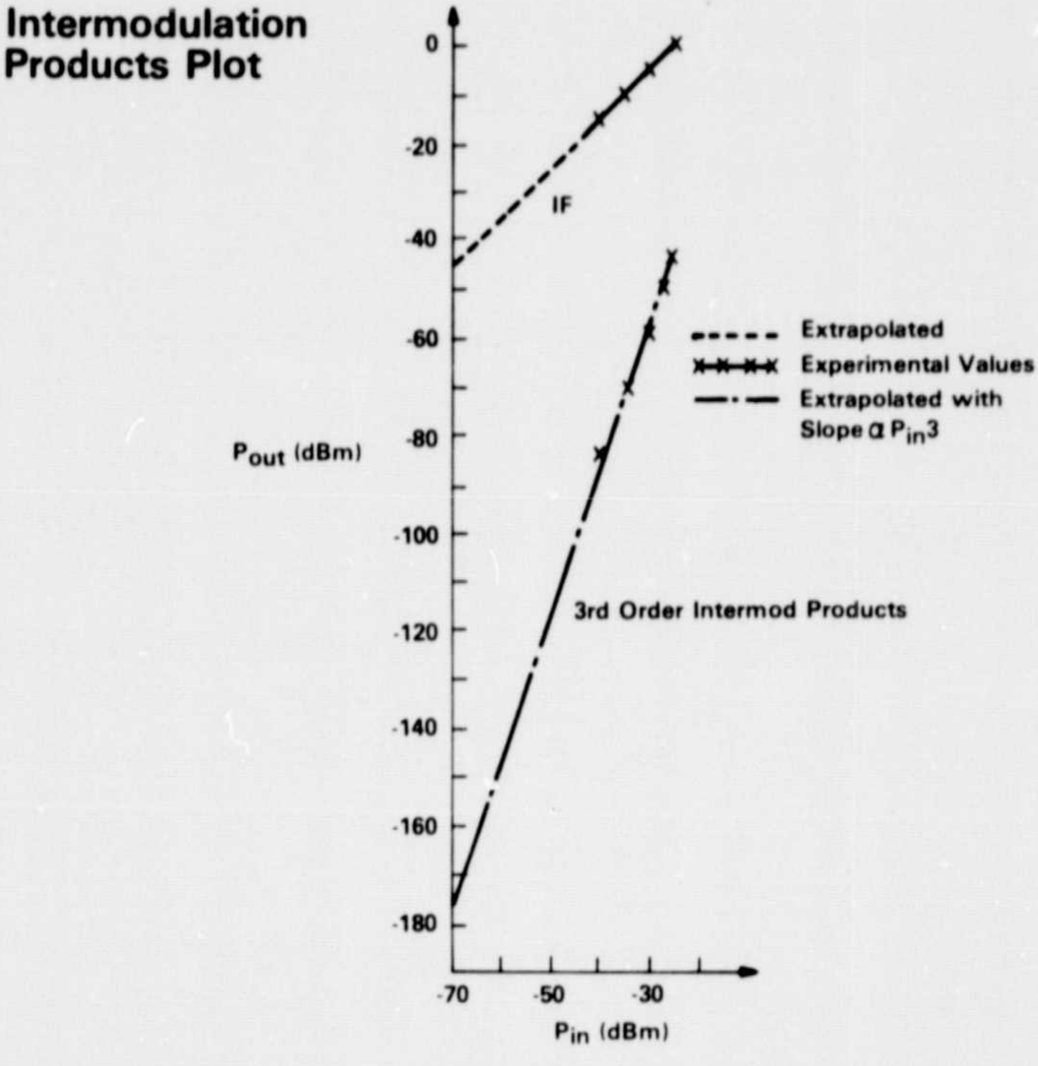

Figure 3-4. Intermodulation Products Plot

0.1 GHz apart. For an input power level of -67 dBm, the intermod products are ≈ 125 dB below the desired IF output. Even when the input power level rises to -30 dBm, the intermod products are still 55 dB below the desired IF output. This far exceeds the mixer specification on linearity.

4.0 CONCLUSIONS AND RECOMMENDATIONS

It can be seen by referring to Table 1 that the performance achieved by the mixer-preamplifier very nearly meets the specification for noise figure and, in the case of the other parameters, greatly exceeds that called for, specifically, $>$ 14 dB return loss, conversion gain $\approx$ 25 dB and 3rd order intermodulation product suppression $\approx$ 125 dB.